

# **The Sandmeier Field Goniometer: A Measurement Tool for Bi-Directional Reflectance**

*Mark Turner  
System Engineering Division  
NASA Ames Research Center*

## **Abstract**

Program Managers in the Commercial Remote Sensing Program Office at NASA Stennis Space Center have identified the need to calibrate and validate remotely sensed data being produced by a growing number of commercial companies. One important variable, which significantly affects the radiometric accuracy of remotely sensed data, is the bi-directional reflectance distribution function (BRDF). To quantify the effects of BRDF on man-made and natural ground targets, the Stennis Verification and Validation (V&V) Team commissioned the Systems Engineering Division at NASA Ames Research Center to develop a Field Goniometer for use at the Stennis Space Center Large Verification Target Range.

The Swiss Field Goniometer (FIGOS) was used as a benchmark instrument to design a new state-of-the-art Field Goniometer, which we designated as the Sandmeier Field Goniometer (SFG), named after Stefan Sandmeier, who developed the FIGOS. After establishing requirements for the SFG, we began design in May 1998. The design of the SFG reached 90% completion in July 1998. We conducted a critical design review with V&V Team members on July 29. Manufacturing, construction, and test will be completed in February 1999. The SFG will be shipped to SSC and become fully operational by March 1999.

## **The Importance of BRDF**

Depending on the viewing angle of the sensor (satellite or aircraft) relative to the target and irradiance source (sun), the intensity of reflected radiance from the target can vary considerably (Sandmeier, 1997). This effect is known as bi-directional reflectance. The distribution of this effect through all illumination and viewing angles is the bi-directional reflectance distribution function (BRDF). BRDF can also vary with seasonal effects, such as rain and snow. BRDF is especially important when using a remote sensor with a large field of view or a platform (satellite or airborne) that can point the sensor away from nadir (the point on the ground directly below the sensor). BRDF effects can also alter the spectral signature of the object being studied.

This variability in reflectance measurements severely restricts the use of remotely sensed data in quantitative scientific studies. A goniometer measures spectral reflectance in a specified number of directions distributed throughout the hemisphere above a particular surface in a very short time (5-10 minutes), allowing scientists to generate a useful BRDF for

that surface. This can significantly improve the accuracy of the measurements made using remote sensors. Spectral reflectance measurements made at a standard, repeatable set of zenith and azimuth angles will allow scientists to create a database of BRDF signatures in the visible and near-infrared bands (400 nm to 2500 nm) for a variety of surfaces.

## **Hardware Development**

The Commercial Remote Sensing V&V Team at NASA Stennis Space Center selected the Swiss Field Goniometer (FIGOS) as the instrument to benchmark for field measurement of BRDF (Figure 1) (Sandmeier et al., 1997). They commissioned the Systems Engineering Division at NASA Ames Research Center to develop a custom field goniometer for use at the Stennis Space Center Large Verification Target Range and at selected remote ground truthing sites. V&V Team members added requirements to customize the FIGOS for their particular needs and to incorporate lessons learned during the operation of the original instrument (Jenner, 1998).



**Figure 1. The Swiss Field Goniometer (FIGOS).**

To be consistent with the BRDF data already obtained using FIGOS, the spectroradiometer on the SFG will traverse the same path. It will also have an identical field of view (3 degrees)

and radius of zenith arc (2 meters – the constant distance between the instrument and the surface being studied).

The key performance requirements of the SFG are:

- The SFG shall provide measurements of the wavelength-dependent reflected electromagnetic energy from a target on the ground in the wavelength range of 400 – 2500 nm with a constant distance of 2 meters between the sensor and the target.
- The SFG shall automatically make spectroradiometer measurements at 66 sample locations (measurements at 11 angles along the zenith arc for 6 azimuth angles) in less than 15 minutes. The primary goal for performance improvement is to accomplish all 66 measurements in 8 minutes. The standard zenith angles are from –75 degrees to +75 degrees in 15-degree intervals, and azimuth angles are from 0-180 degrees in 30-degree intervals.
- The SFG shall have a pointing accuracy through all zenith (-75 degrees to +75 degrees) and all azimuth (0-360 degrees) angles of less than +/- 3.5 cm in any direction, as measured by a laser spot on the ground target, which represents the center of the spectroradiometer field of view (FOV).
- When the spectroradiometer is at nadir, its FOV of the ground target shall be 10.5 cm in diameter or less.
- The SFG structure shall not shadow the target when measuring in the solar principal plane (azimuth of spectroradiometer aligned with azimuth of the sun). The spectroradiometer sensor head will be designed, to the extent possible, to reduce the amount of shadowing on the target at other angles.
- The SFG shall operate on terrain with slopes of up to 10% grade.
- The SFG shall have repeatable performance throughout disassembly and reassembly in environments with a range of temperatures between –2 degrees C and 38 degrees C and within a range of relative humidity between 10% and 95%.

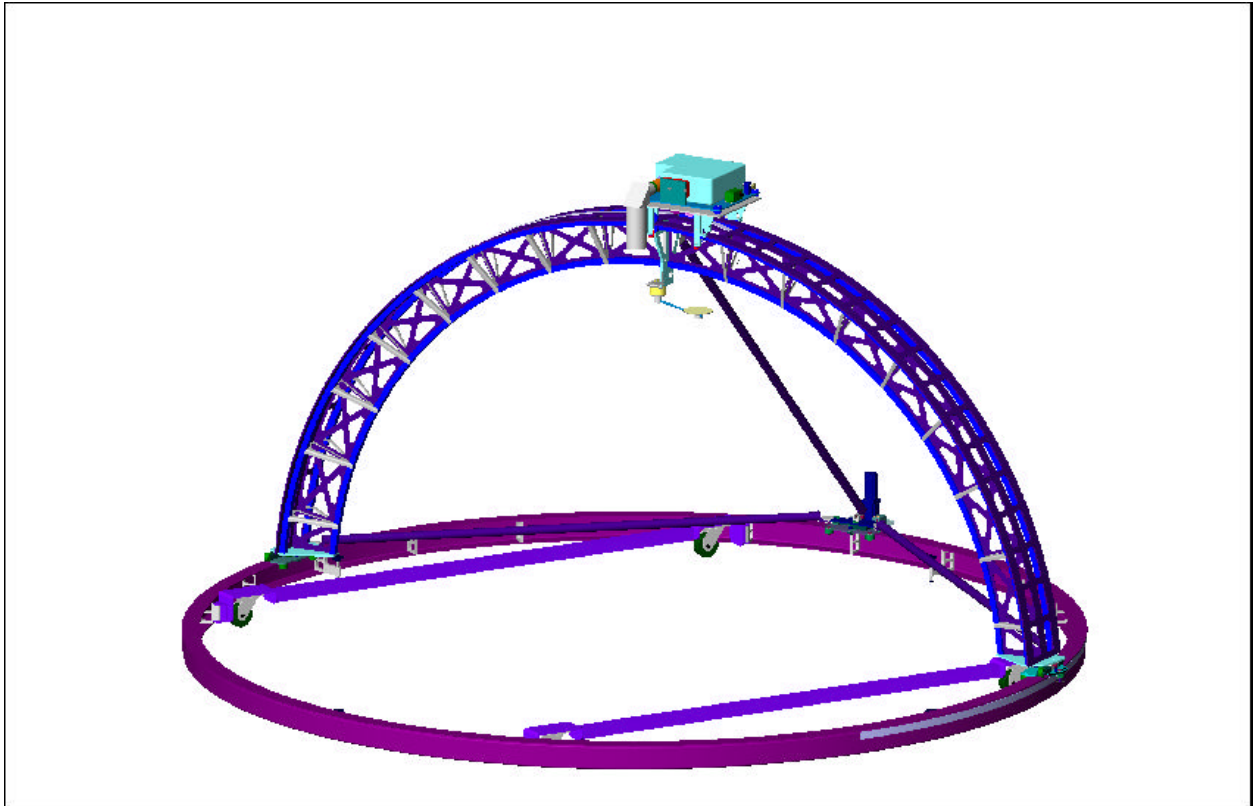
The V&V Team added functional and operational requirements to make the SFG easier to use during ground truth collections and to assure repeatability in data collection.

## **Design Description**

The SFG uses an off-the-shelf GER 3700 spectroradiometer capable of taking measurements in the wavelength range of 400 – 2500 nm. A custom fore-optic right-angle lens is connected to the spectroradiometer to decrease shadowing effects that would occur if the instrument body were placed between the sun and the target. The instrument sled, which supports the GER 3700, incorporates an alignment plate to allow for fine-tuning of the instrument's optical path relative to the target. A 0.4-hp brushless DC motor powers the instrument sled that supports the GER 3700. An identical motor that is located on the Base Ring Drive Sled drives the zenith arc. Commands entered through a portable laptop computer drive the instrument sled through a preprogrammed path. The default path allows for measurements to be taken every 15 degrees along the zenith arc and every 30 degrees along the azimuth base



(the standard FIGOS measurement angles). LabView software allows the user to request spectroradiometer measurements at any combination of zenith and azimuth angles or in a non-standard, pre-programmed sequence. Positioning of the instrument sled and zenith arc is accomplished using incremental encoders for position feedback and single axis servo inclinometers for precision location. Both drive systems use a Urethane timing belt for precision synchronization with the motor encoder.



**Figure 2. Design concept for the Sandmeier Field Goniometer.**

Speed of data acquisition was identified as one of the key design drivers. The longer it takes to make BRDF measurements, the greater the possibility that the solar illumination environment has changed. The automated control system, as currently designed, allows for all 66 standard measurements to be taken in 8 to 10 minutes. Because the sun is continuously moving and changes in the atmosphere can occur over a very short time, the SFG has an automated calibration device: a Spectralon target rotates into view of the spectroradiometer every time the sled passes the nadir position on the zenith arc. The Spectralon target is placed 11 inches from the instrument's fore optic lens, allowing calibration without shadowing when used at latitudes greater than 16 degrees north or south.

The Zenith Arc assembly is designed to be separated into two halves to facilitate transport. Each half weighs 32 pounds. Guide pins located at the upward mate surface allow for precise repeatable alignment. Captive fasteners are provided for all mate locations. The Azimuth Ring is four meters in diameter (Figure 3) and can be disassembled into four quarter sections.

Each quarter section weighs 23 pounds. Four leveling jackscrews are provided to prevent rocking of the SFG on uneven terrain. To keep the number of people required for assembly at two, the Zenith Arc is attached to the Azimuth Ring Side Sleds using two pinned connections on a clevis assembly. This allows for quick assembly by one person while the other person holds the truss in position.



**Figure 3. The Design and Development Team at NASA Ames Research Center shown with a full-scale virtual Sandmeier Field Goniometer.**

The SFG can be easily moved on hard surfaces using the built-in caster assembly. Using C-channel rails, the SFG can be moved from different locations on uneven surfaces. All components have been designed to minimize weight to allow for assembly in remote locations. The SFG can run on 120 VAC or on DC Gel Cell battery packs.

### **Fabrication and Delivery Schedule**

The design of the SFG is currently 90% complete. A Project Plan will be developed which outlines the schedule, cost, and deliverables for the manufacture and test of the SFG. Manufacture of the SFG will begin in October 1998. The SFG should be fully operational at the Stennis Space Center Large Verification Target Range by March 1999.

- Feb. 26, 1998 Initial discussion with Stennis V&V management
- March 30, 1998 Project Plan completed and submitted to Stennis Space Center (SSC)
- March 31, 1998 Funding to Ames Research Center for design of the SFG

- May 7, 1998 Requirements and Concept Review at SSC
- July 22, 1998 Design 90% complete, Critical Design Review Package delivered to SSC
- July 29, 1998 Critical Design Review via telecom with SSC
- Oct. 1, 1998 Proposed construction start of SFG
- Dec. 30, 1998 Proposed construction completion of SFG
- Feb. 1, 1999 Proposed test and verification completion of SFG
- Feb. 19, 1999 Proposed delivery

**See SLIDES for animations of the design concept, assembly sequence, and operational scenario.**

## **References**

- Jenner, Jeff, 1998. *NASA Commercial Remote Sensing Verification and Validation Radiometric and Atmospheric Instrument Requirements and Concept Review*, Commercial Remote Sensing Program Office, NASA Stennis Space Center, May 7-8.
- Sandmeier, St., W. Sandmeier, K. I. Itten, M. E. Schaepman, and T. W. Kellenberger, 1996. Acquisition of Bidirectional Reflectance Data Using the Swiss Field-Goniometer System (FIGOS), in: *Proc. of EARSeL Symposium*, Basel, Switzerland, Balkema Publ. NL, pp. 55-61, download from <http://www.geo.unizh.ch/rsl/projects/figos.html>
- Sandmeier, Stefan, 1997. *Introduction to BRDF Effects*, download from <http://www.geo.unizh.ch/~sandi/BRDF/intro.html>